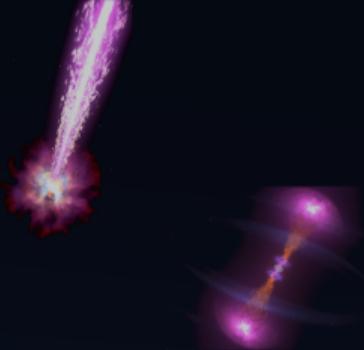
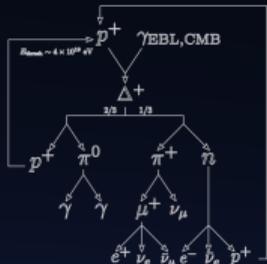


Prowling for Ultrahigh Energy Neutrinos with PUEO

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for the PUEO Collaboration

APS April 2021



PAYLOAD FOR ULTRAHIGH ENERGY OBSERVATIONS (PUEO)

- Leveraging >18 years of experience with the ANITA instrument, the [Payload for Ultrahigh Energy Observations \(PUEO\)](#) is a new long-duration balloon experiment designed with world-leading sensitivity to UHE neutrinos above 1 EeV [1].
- Following on from ANITA, the design of PUEO drastically improves the sensitivity by more than an order of magnitude at energies below 30 EeV compared to ANITA-IV and includes dedicated features to improve the analysis of detected events.
- [PUEO has been selected for further concept design in NASA's Pioneers program with a proposed launch in 2024.](#)

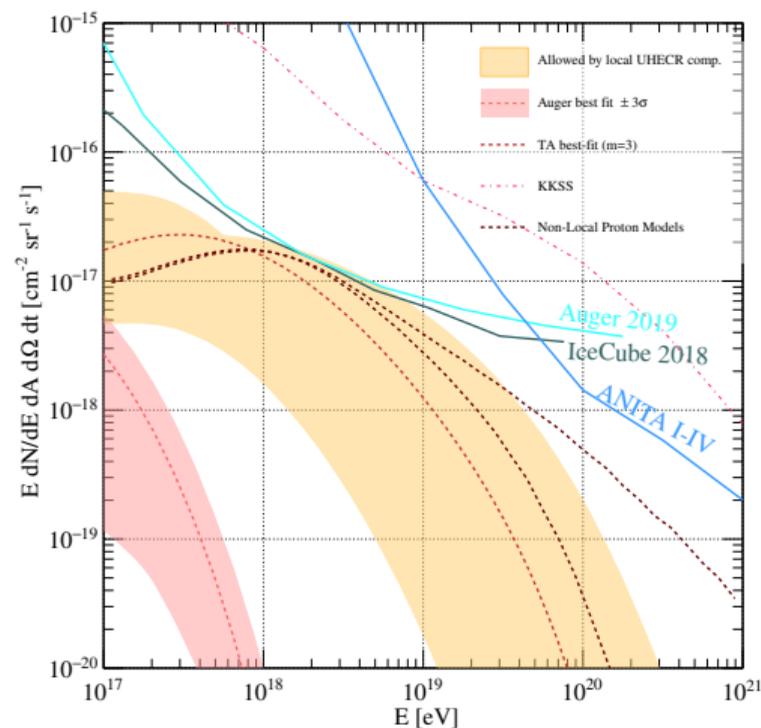
Science Goals

PUEO will either make the [first significant detection of](#) or [set the best limits on](#) the ultrahigh energy neutrino flux above 1 EeV.

SUMMARY OF ANITA RESULTS

- Over four successful flights, ANITA has set the most stringent constraints on the ultrahigh energy neutrino flux between 40 EeV and 100 ZeV and has ruled out many neutrino production models and mechanisms [2].
- ANITA has also observed ~60 UHECRs [3], constrained fundamental physics [4], placed limits on astrophysical processes [5], measured Antarctic surface properties [6], and detected unique anomalous events [7, 8].

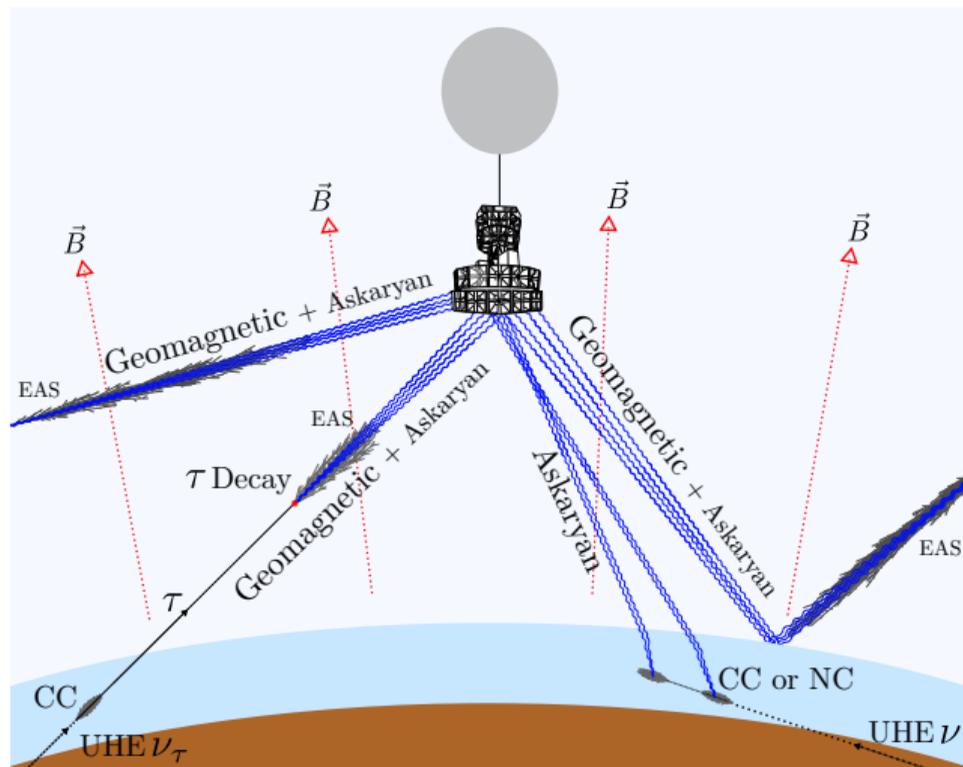
Current Limits on UHE Cosmogenic Neutrinos



DETECTION GEOMETRIES

Just like ANITA, PUEO is sensitive to UHE neutrinos and cosmic rays through several unique geometries:

1. $\nu_{e,\mu,\tau}$ via the in-ice Askaryan method.
2. UHECRs viewed directly from the stratosphere.
3. UHECRs viewed in reflection off the ice surface.
4. Upgoing showers from the decay of a τ -lepton from an Earth-crossing ν_{τ} .



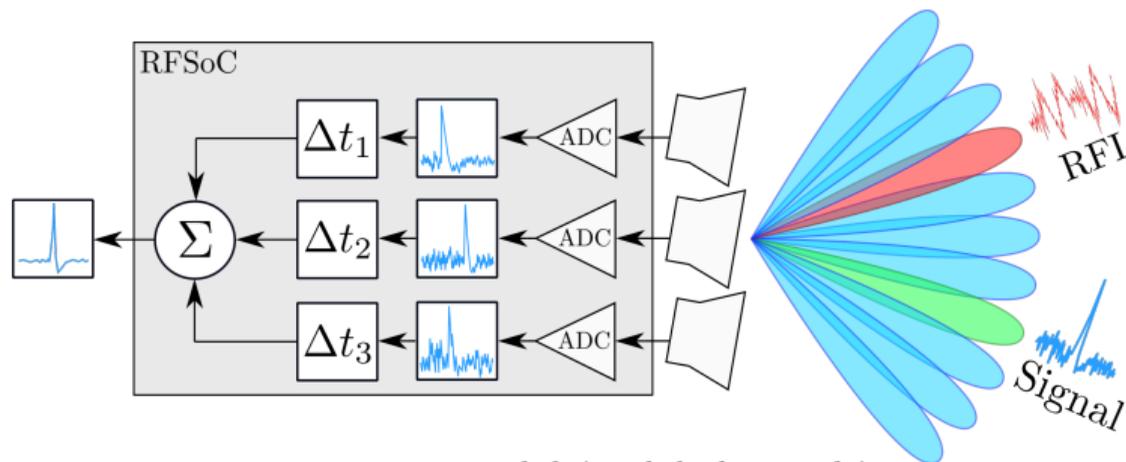
SIGNIFICANTLY IMPROVED CHANNEL COUNT

- PUEO's main instrument will use 108 dual-polarization quad-ridge horn antennas, based upon the ANITA-IV design, with a nominal bandwidth of 300-1300 MHz.
- By moving the antenna's lower-frequency limit from the ~200 MHz used in ANITA-IV up to ~300 MHz (halving the physical antenna area), PUEO more than doubles the total antenna count compared to ANITA-IV.
- The sensitivity hit from the loss of the heavily RFI-contaminated 200-300 MHz band is more than compensated for by the larger antenna count.



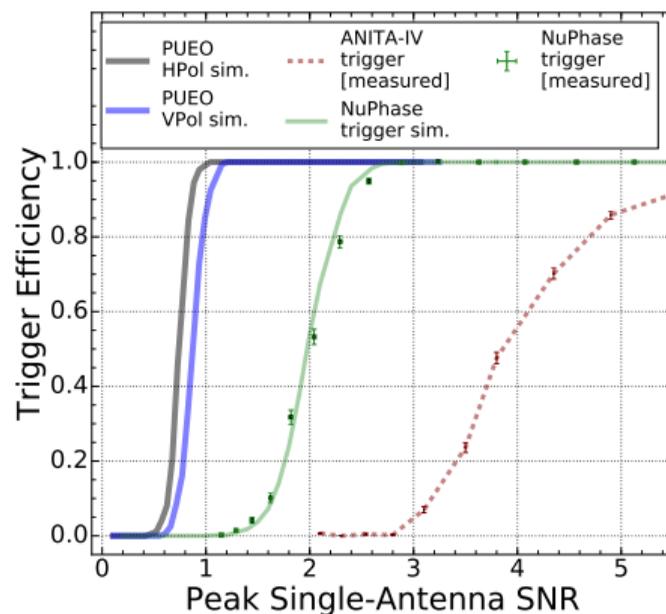
INTERFEROMETRIC PHASED ARRAY TRIGGER

- PUEO will deploy a new **interferometric (coherent delay-and-sum) trigger** that significantly lowers the detection threshold compared to ANITA-IV.
- The design leverages the PUEO Collaboration's experience designing the NuPhase interferometric trigger for the Askaryan Radio Array [9].
- The interferometric trigger also provides significantly improved rejection of RFI which will be rejected in real-time at the trigger level.



- In addition to performing the beamforming necessary for the interferometric trigger, PUEO will use its RFSoc-based DAQ system to perform:
 - **Dynamic notch filtering** to remove continuous-wave interference (as previously done in dedicated hardware for ANITA-IV [10]).
 - **Real-time group delay compensation** of the system response at the trigger level.
 - Trigger-path **band-pass filtering to optimize the trigger** for Askaryan and EAS-like signals.

PUEO's Interferometric Trigger Simulation

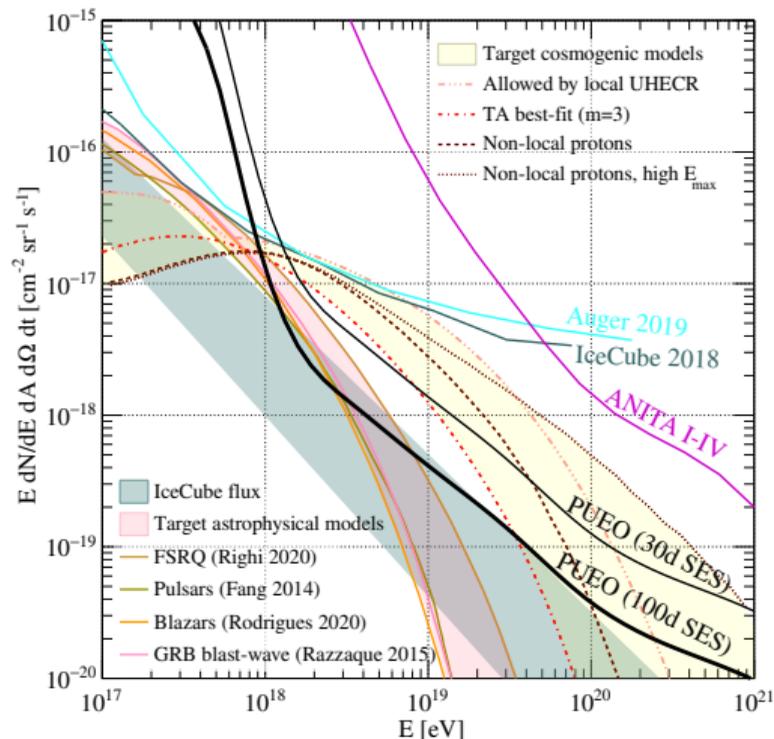


PUEO achieves a 50% threshold at a voltage SNR of 0.8 as viewed in a single V-Pol antenna.

DIFFUSE NEUTRINO FLUX PERFORMANCE

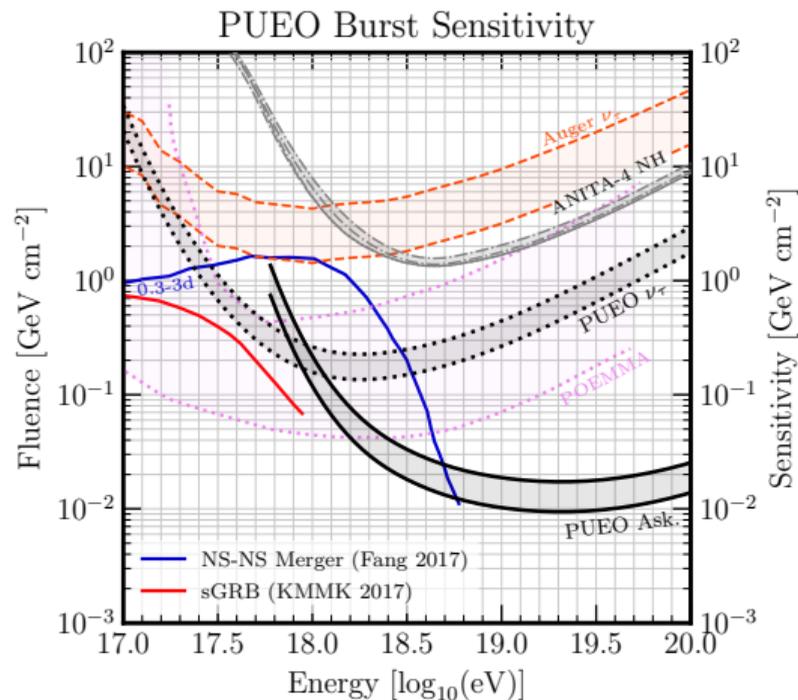
- A single 30-day flight of PUEO will either **measure** or **eliminate** a **number of cosmogenic models** from non-local or sub-dominant proton sources.
- A 100-day cumulative campaign **can confirm or exclude the best-fit TA** composition and could also **measure diffuse astrophysical neutrinos** from FSRQs, Pulsars, or GRBs [1].

PUEO's Sensitivity to Diffuse UHE Neutrinos

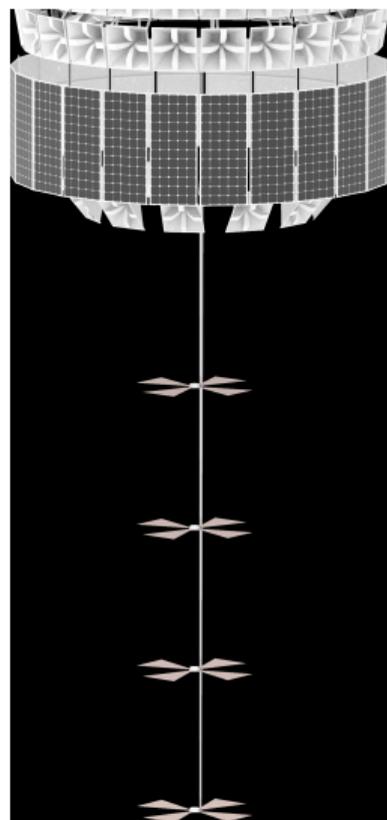


TRANSIENT NEUTRINO SOURCE PERFORMANCE

- PUEO's *very large instantaneous aperture* makes it well-suited to measuring UHE neutrino fluences from transient astrophysical sources that occur in its field-of-view.
- The grey bands in the figure indicate the range of achieved sensitivities across PUEO's primary field-of-view.
- In particular, current models for neutron-neutron star mergers [11] and short GRBs [12] are promising candidates for detection by PUEO.



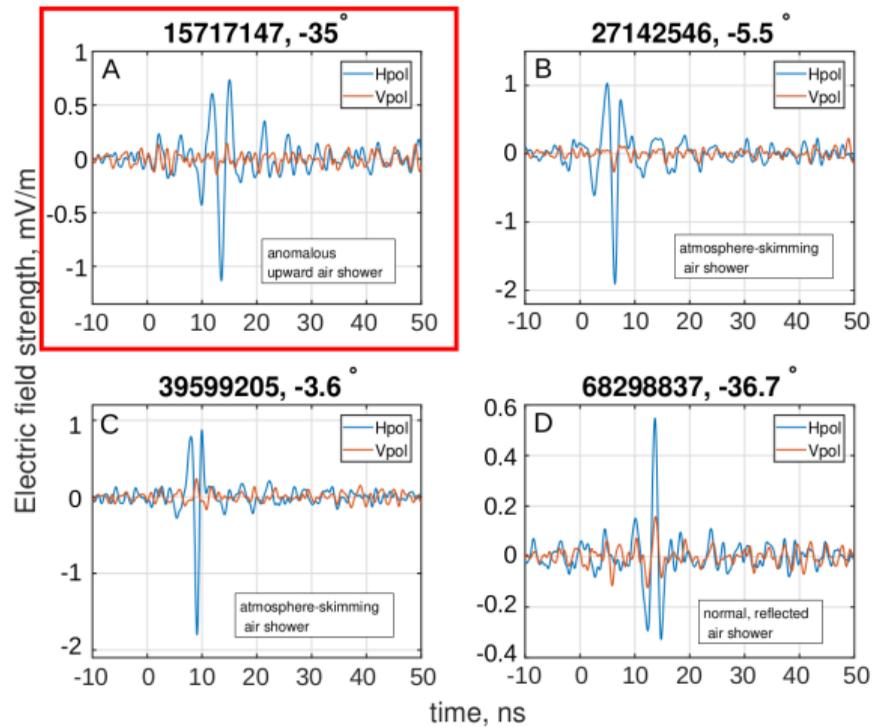
- PUEO also includes a multi-channel **low-frequency (50-300 MHz) dropdown instrument** as well as a dedicated **steeply-canted ring of full-bandwidth antennas** (pointed at -40° below the horizontal) designed to enhance PUEO's sensitivity to EAS-like events that have strong spectral power below 300 MHz.
- The DAQ used for the low-frequency instrument is integrated with the main interferometric trigger and has the ability to trigger the full payload.
- This builds upon the heritage of the ANITA Low-Frequency Antenna (ALFA) that was flown as part of the ANITA-III flight.



STEEPLY UPGOING ANOMALOUS EVENTS

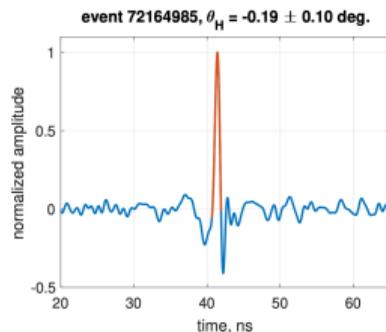
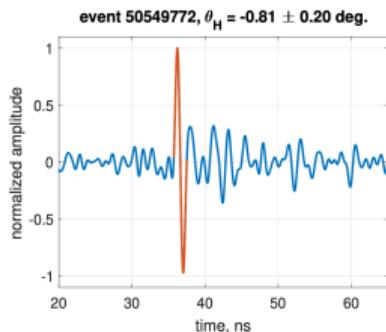
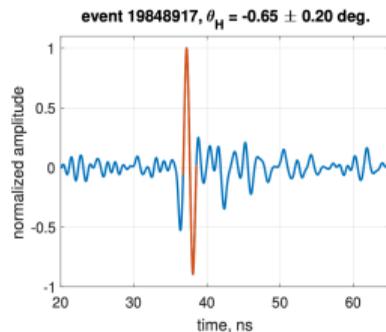
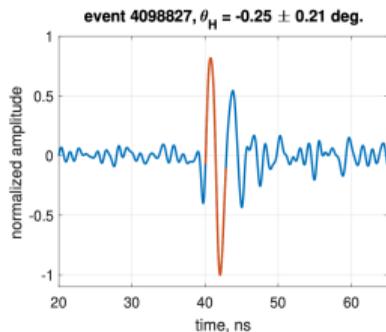
- ANITA-I and ANITA-III also observed a pair of **steeply upcoming** events with polarity consistent with an **upcoming extended air shower (EAS)** but at emergence angles in strong tension with Standard Model explanations [13].
- These events currently lack a Standard Model explanation [14] but have been used as evidence for many BSM theories [15, 16, 17, 18].

ANITA-III Anomalous Event



- ANITA-IV also observed **four upgoing events** that were observationally consistent with EASs [8].
- Unlike the steep events observed in previous ANITA flights, these four events were observed **close to the horizon** significantly reducing the tension with Standard Model ν_τ explanations.
- A detailed analysis of these events under a ν_τ hypothesis is underway.

ANITA-IV Upgoing Near-Horizon EAS-like Events



PUEO's ANOMALOUS EVENT SENSITIVITY

- With its steeply canted and low-frequency antennas, PUEO will have **significantly improved sensitivity to these events**.
- PUEO will also have improved attitude and pointing resolution which will allow for greater analysis efficiency and reduced contamination from man-made backgrounds.

PUEO can provide important evidence for these events

The detection or *non*-detection of these events by PUEO will provide important evidence in the ongoing interpretation and analysis of these events.

Prototype PUEO Star Tracker



A significantly upgraded IMU in combination with a pair of daytime star trackers will significantly improve PUEO's elevation resolution.

- PUEO will either make the **first significant detection of** or **set the best limits on** the ultrahigh energy neutrino flux above 1 EeV.
- PUEO achieves this sensitivity by deploying:
 1. Significantly more antennas compared to ANITA-IV.
 2. An interferometric trigger system.
 3. Real-time filtering and group delay compensation at the trigger level.
 4. A ring of steeply-canted antennas and a dedicated low-frequency system to increase sensitivity to τ -induced EASs.

Please see our [White Paper](#) for more information.



A *pueo*, a short-eared owl endemic to Hawai'i, and one of the common forms of 'aumākua (ancestor spirits) in Hawaiian culture [Image Source].

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